Nature Conservation 47: 317–333 (2022)
doi: 10.3897/natureconservation.47.70704
https://natureconservation.pensoft.net

RESEARCH ARTICLE

A peer-reviewed open-access journal
Nature Conservation
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Preliminary results on the bird protection effectiveness of animal deflectors on railway overhead lines based on electrical current evaluation

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Academic editor: Sara Santos | Received 15 August 2021 | Accepted 11 January 2022 | Published 25 March 2022

http://zoobank.org/3F40FDCB-1BA8-44A1-B562-90DAC22190A8

Citation: Kornhuber S, Pampel H-P, Görlich J, Leiblein-Wild M, Jöckle C (2022) Preliminary results on the bird protection effectiveness of animal deflectors on railway overhead lines based on electrical current evaluation. In: Santos S, Grilo C, Shilling F, Bhardwaj M, Papp CR (Eds) Linear Infrastructure Networks with Ecological Solutions. Nature Conservation 47: 317–333. https://doi.org/10.3897/natureconservation.47.70704

Abstract

In contrast to other transportation systems, railway systems feature special characteristics, which may cause specific hazards to birds. Among other things, there is the risk of electrocutions resulting from short circuits. To protect the birds and minimize these short circuit events, the DB Netz AG has installed so-called animal deflectors on the insulators of the overhead lines. Since this effort, the number of short-circuit events in the respective sections has decreased, according to DB Netz AG. The principal mechanism of action of the animal deflectors is based on mechanical defense, combined with electrostatic discharge on contact. Although the number of short circuit events has been reduced by using animal deflectors, the detailed function of the animal deflector in different environmental conditions has not been investigated up to now. This research project aims to determine whether, and to what extent, the use of animal deflectors in retrofitting overhead lines may contribute to bird protection and which currents can be measured at retrofitted insulators under different environmental conditions. Hence the current should be measured when using animal deflectors on railway overhead lines for different isolator states and body resistances (5 kΩ, 3 kΩ, 1kΩ, 0.5 kΩ). The results show an influence of measured current depending on the insulator state. Our preliminary results indicate that the use of an animal deflector (KTA) to the tested polymeric insulator and pollution severity can be recommended, since, based on the investigations, no danger to small birds and small animals can be identified. However, the use of the animal deflector (KTA) for the tested porcelain insulator and pollution severity should not be recommended as they showed high animal hazards during pollution and fog conditions. However, these results cannot be transferred to other

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different insulator types and pollution severities. Investigating the electrical current to the type of insulator used and the expected pollution severity is recommended.

Keywords
Animal deflector, overhead railway line, polymeric insulator, porcelain insulator, stationary current, transient impulse current

Introduction

Compared to other transport infrastructures, electric railways have unique features that can cause specific hazards for birds. Overhead line systems of electric railways provide birds with a variety of resting places. In particular, simultaneous contact with system components of different electrical potentials can risk damaging currents flowing, or even trigger a short circuit.. In order to reduce the number of circuits caused by birds and small mammals, the company DB Netz AG is increasingly using a so-called animal deflector (German: Kleintierabweiser – KTA, shown in Fig. 1) mounted on the insulating part of the high-voltage insulators.

The animal deflector (KTA) does not protect larger birds and does not meet the requirements of the Federal Nature Conservation Act (§ 41 BNatSchG, according to which only constructive measures are to be provided for new installations). Thus, it only can be used for retrofitting existing overhead lines. The animal deflector provides a mechanical defense in combination with a repelling effect caused by discharging static electricity. DB Netz AG estimates KTA as a suitable tool to protect birds and small animals efficiently, as the number of short-circuit events of retrofitted sections seems to decrease. Some nature conservation organizations, however, criticize the functionality of animal detectors and suspect an additional hazard to birds and small mammals, instead.

However, up to now, the detailed function of the animal deflector under different environmental conditions has not been investigated. To close this gap of knowledge and to enable data-based evidence on the question of the suitability of animal detectors for bird protection, a research project of the German Centre for Rail Traffic Research (DZSF) was conducted. In this research project, the following questions were addressed:

- Which levels of electrical currents occur when a small bird touches the KTA?
- How does pollution of the insulator and environmental influences impact the electrical current?
- Do the currents exceed the stimulus threshold of small birds?
- Are small birds endangered by the occurring currents?
- Are short circuits to be expected if the KTA is touched by a small bird?
- Which recommendations and further possibilities can be derived from these results?

However, no reproducible and repeatable measurement results gauging electrical current through the small animal or small bird during contact with the animal

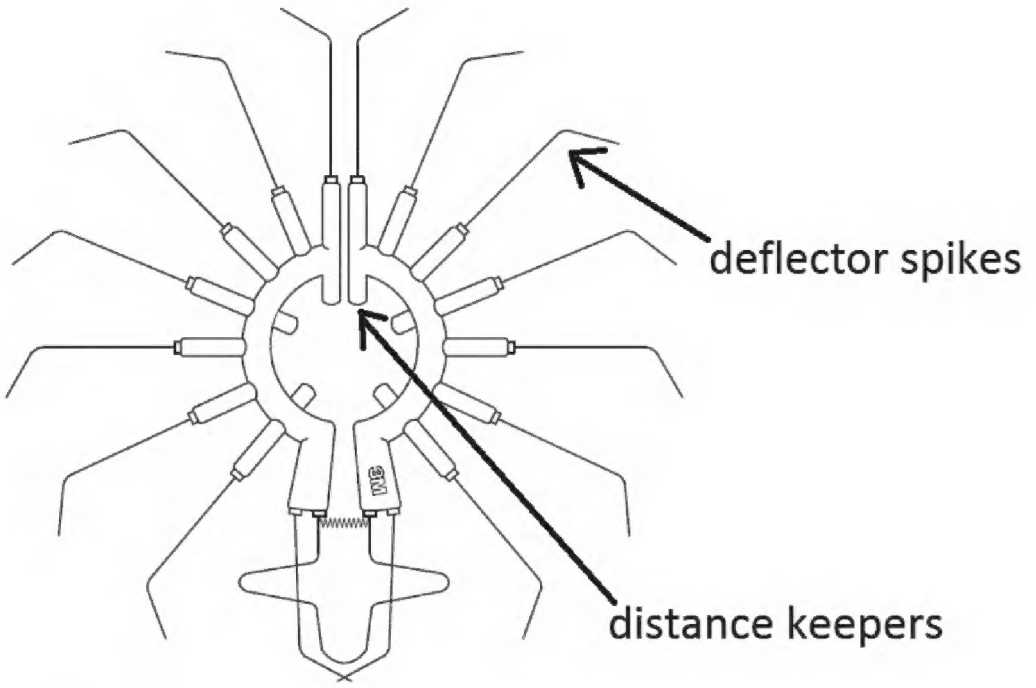

Figure 1. Setup of an animal deflector.

deflector (KTA) at different polluted and wetted insulators are available. So, the aim of the presented experiments and results is to determine practice-relevant electrical parameters that can affect birds when they touch an animal deflector (KTA) mounted on an insulator. Furthermore, a measurement setup and process, and an electric model schematic, which allows a calculation-based investigation, have been developed.

Investigation methods

To control the scope of the experiment and the variety of parameters, conditions close to "real conditions" are defined for the respective influences and simulated as far as possible by means of introduced reproducible experimental methods. For this reason, international common-sense standards and documents (e.g. IEC and CIGRE) and the investigation procedure based on a consensus of an interdisciplinary project advisory group (e.g. ornithology experts, railway experts, bird-life conservation NGOs) were used.

The following parameters are defined as relevant to practice, i.e., influencing the magnitude of the electrical effects in practice (reality):

- the type of insulator with associated KTA (hereinafter referred to as test specimen), the condition of the surface of the test specimen,
- environmental influences acting on the test specimen,
- the arrangement of the test body in the system,
- the size of the small bird's body resistance, and
- the position of the small bird before approaching the KTA.

The electrical resistance of birds can vary due to their physical characteristics (size, density, and type of feathers, total proportion of water contained in the body). The

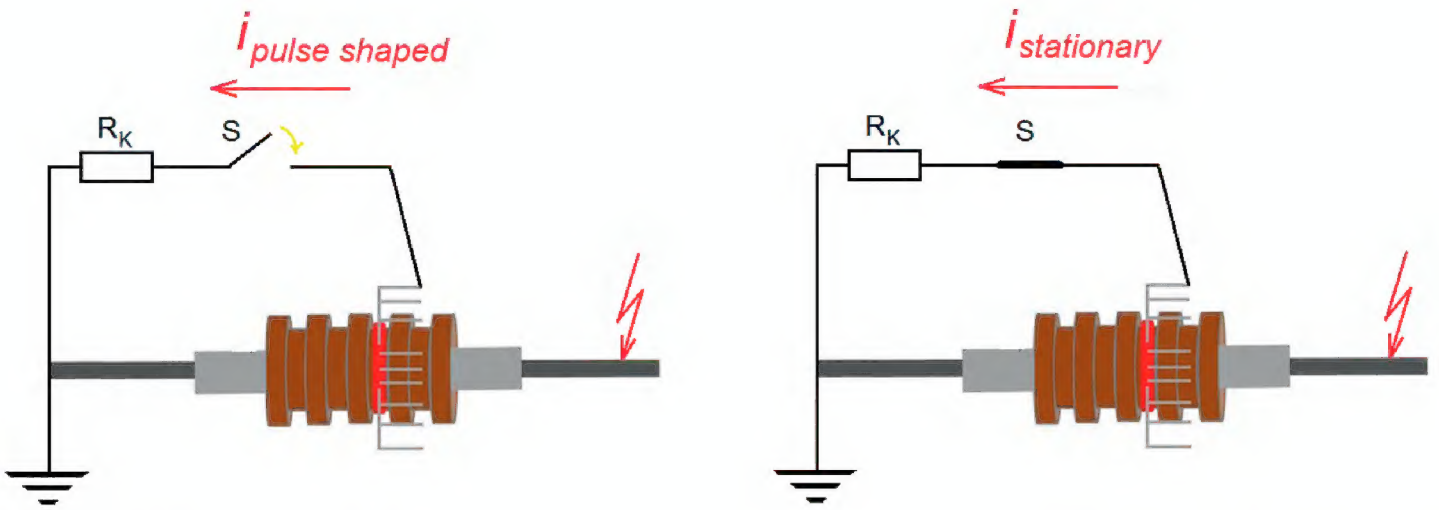

Figure 2. Measured electrical current at the moment of contact (left) and during the steady-state condition (right), S: Switch; RK: Animal Resistor.

small birds and animals are simulated by technical resistors. The measurements are carried out with four different equivalent resistors (5, 3, 1, and 0.5 kΩ).

The electrical quantities recorded during the experiments are the alternating voltage across the insulator and the transient behavior of the current flowing through the equivalent resistor from the moment of contact with the KTA. The current at the time of contact is pulse-shaped (Fig. 2 – left) and changes to a stationary behavior after longer contact with the KTA (Fig. 2 – right). The case of a bird sitting on earth potential is simulated, as from the electrical point of view, this is the more critical combination. The simulation of the contact is realized experimentally with a switch (Fig. 2).

The dimensions, the material, and the design of the insulator can have a strong influence on the amount of charge available on the electrodes of the KTA and thus on the pulsed current flowing at the time of contact with the KTA. Furthermore, the electrical current flowing through the bird when the KTA is then permanently touched also depends on the material and the dimensions of the insulator. A special dependency exists regarding the behavior with pollution and/or moistened insulating material surfaces. For example, the surfaces of polymeric insulators might be water-repellent (hydrophobic). This property can be transferred to the layers of dirt adhering to the insulating material. Due to this hydrophobic transfer, there is no or not such a strong reduction of the insulating capacity compared to the porcelain insulator. When a polluted porcelain insulator is moistened, on the other hand, a closed conductive layer can be formed, which can lead to a lower insulating capacity with increased flow through the bird and to an increased risk of a flashover. For the investigations done within this research, one typical polymeric insulator type (Fig. 3) and one typical porcelain insulator type (Fig. 4) from DB Netz AG were used.

Measurement setup and process

In Fig. 5, the test circuit is shown. The test voltage is applied from the main supply by using a regulation transformer and a high voltage transformer. The voltage of 16 kV at 50 Hz is applied. In the project report (Görlich et al. 2021), an investigation on the influence of the frequency difference between 16.7 Hz and 50 Hz was conducted and concluded:

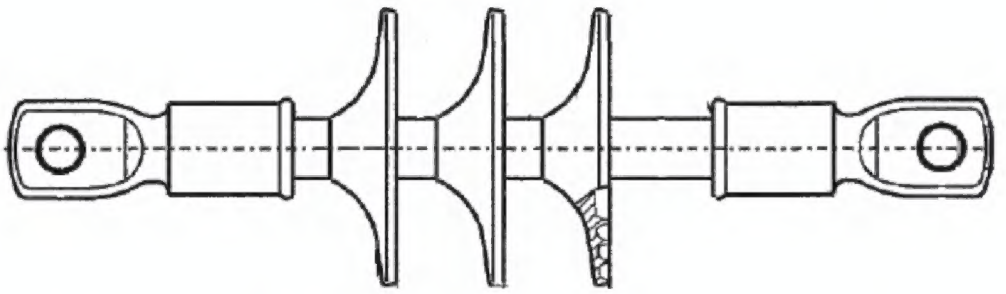

Figure 3. Polymeric Insulator under investigation.

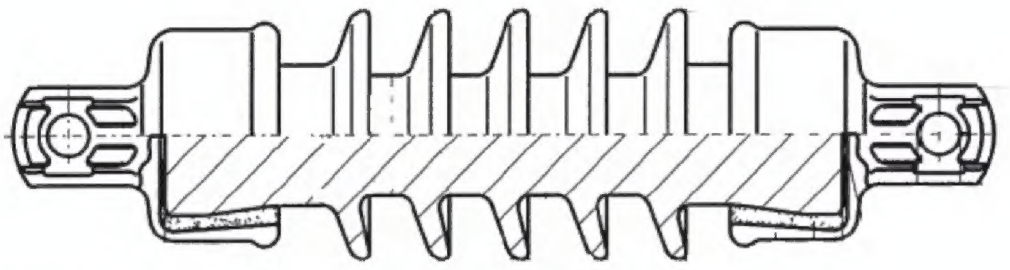

Figure 4. Porcelain insulator under investigation.

- for the impulse discharge behavior no influence of the frequency is observed because the accumulated charge, which is independent of the supplying frequency, is responsible for the behavior.
- for the pollution flashover characteristics, the resistive behavior is mandatory. This is frequency-independent.
- for the behavior which is mainly dominated by the displacement current (clean insulator, polluted and dry insulate), the frequency has a direct influence. However, the currents are both very small (tens of μA) compared to the reference values and limits.

The animal deflector is mounted in accordance with the procedure, and two independent metal spikes are connected to each other for reflection in the worst case in a real application, which is leading to an increased electrical charge. By using a switch, the spikes of the animal deflector are conducted with a combination of resistors which provide the body resistance of the birds and also include the measurement shunt for measuring the current, which is recorded by using a transient analyzer.

In Fig. 6, the test setup at dry tests and rain tests is shown, which was set up quite close to the real setup at a railway. With this additional setup, a comparison to the fog chamber optimized setup for evaluating the influence of stray capacitances was provided.

In Fig. 7, the setup in the fog chamber is shown.

During the investigations the following conditions were applied to the polymeric insulator:

- cleaned insulator in dry, rainy, and icy conditions
- light-polluted insulator in dry, rainy, and wetted by fog conditions
- heavy-polluted insulator in dry, rainy, and wetted by fog conditions

During the investigations following conditions were applied to the porcelain insulator:

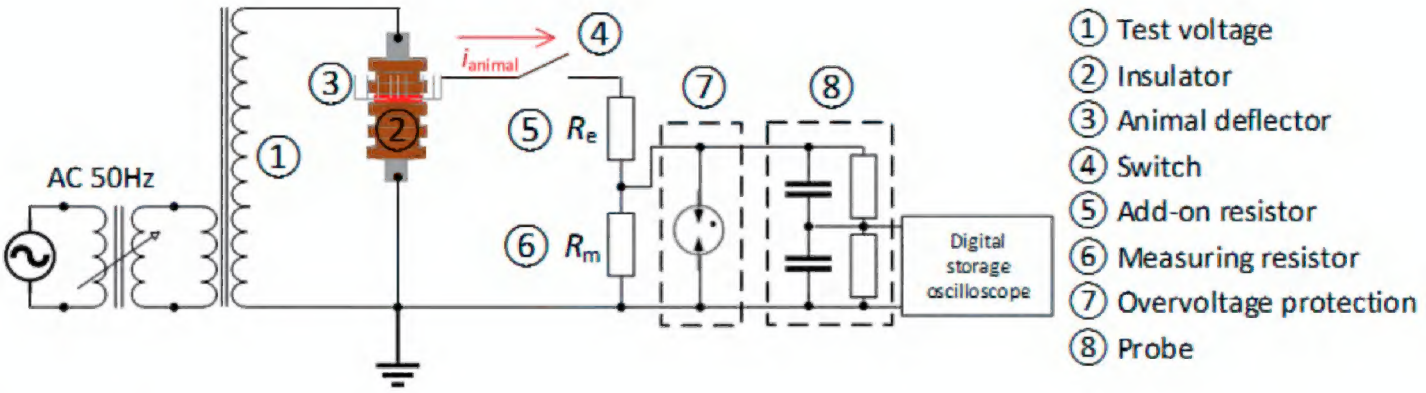

Figure 5. Setup of the Test Circuit.

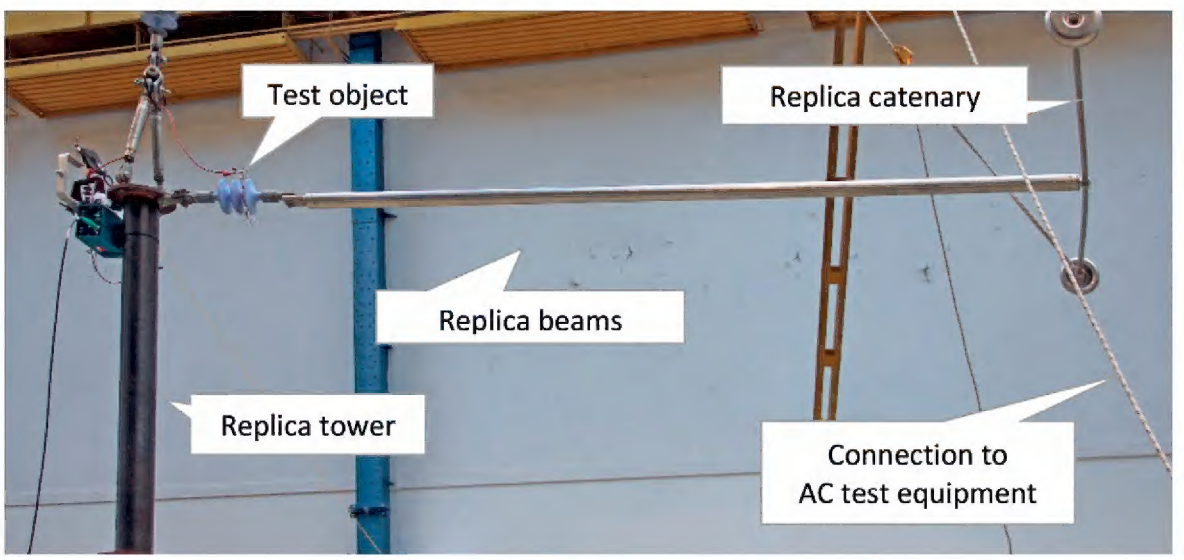

Figure 6. Test setup for dry test and rain test at TU Dresden.

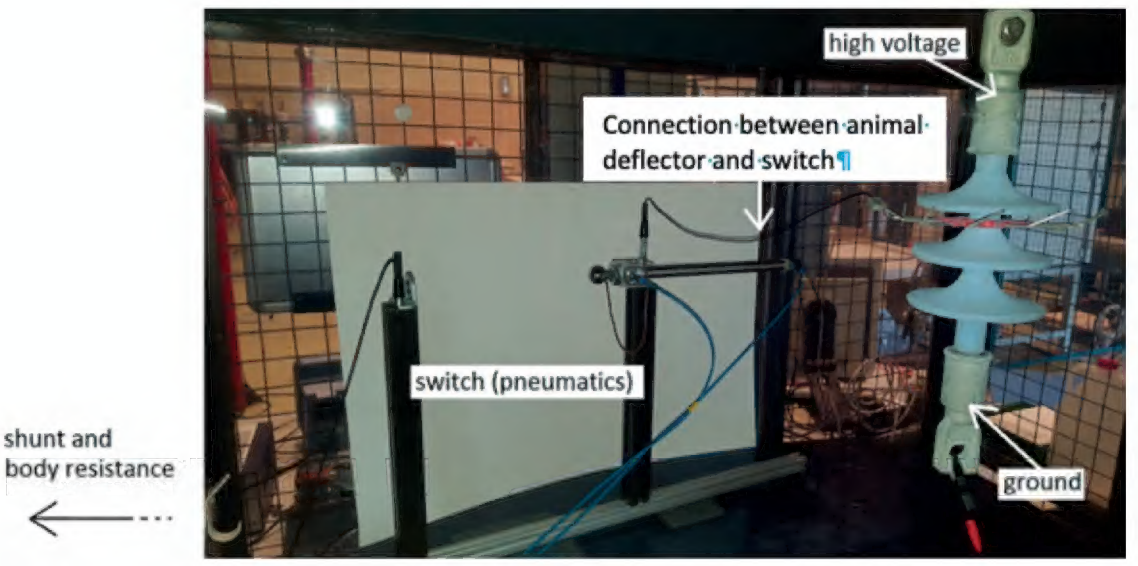

Figure 7. Test setup in the fog chamber.

- cleaned insulator in dry
- light-polluted insulator in wetted by fog conditions
- heavy-polluted insulator in wetted by fog conditions

The polluted conditions were applied by using the recommendations of the CIGRE Technical Brochure 555 (2013) proposing a procedure for the contamination of

Table 1. Overview of the used artificial pollution suspension for light and heavy pollution.

Light pollution	Heavy pollution
1000 g Water	1000 g Water
20 g Highly dispersible silica	25 g Highly dispersible silica
0,2 g NaCl	2,5 g NaCl
Conductivity of suspension: 450 µS/cm (at 20 °C)	Conductivity of suspension: 4,1 mS/cm (at 20 °C)

insulators for laboratory tests, which refers to the preparation of suitable contamination layers according to IEC 60507 (2013), Chapter 6. In accordance with IEC 60507 (2013), chapter 6.3, a suspension with light contamination and a suspension with strong contamination (Table 1) are prepared for the investigations. The conductivity of the contamination is adjusted via the salt (NaCl) content. The required quantities were determined by preliminary tests.

A corresponding number of test specimens is taken from the quantity of cleaned, prepared insulators. The contamination suspension is applied to these using the immersion method in accordance with IEC 60507 (2013). For this purpose, the insulators with KTA are immersed in the respective contamination suspension and immediately pulled out again. (Fig. 8).

The impurity layer is then dried and stored for 24 h under the atmospheric conditions prevailing in the test room (air temperature 23 °C to 24 °C, humidity 45% to 50% r.h.).

At the test specimen standard rain according to IEC 60060-1 (2011), section 4.4. with the following parameters were applied:

- mean rainfall vertical 1.5±0.5 mm/min horizontal 1.6±0.5 mm/min
- The specific electrical resistance of the rainwater 100±5 Ohm
- The temperature of rainwater 16 °C
- Pre-stress time in stress-free condition 15 min

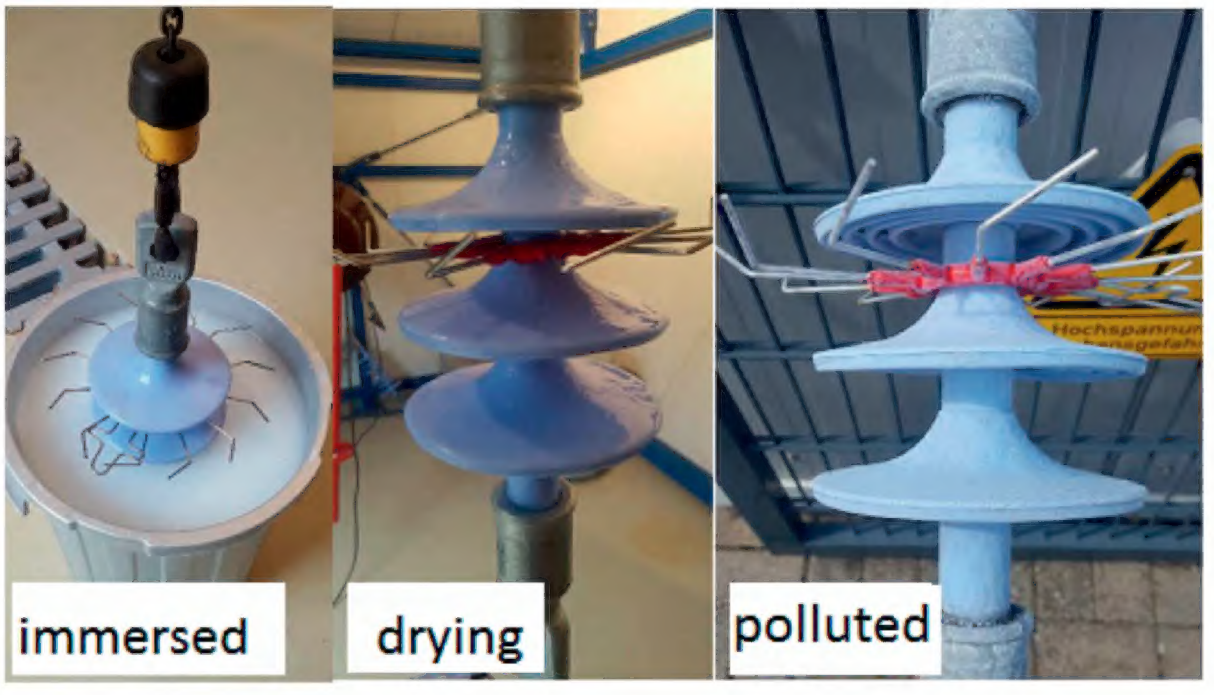

Figure 8. Applying the contamination layer - example, polymeric insulator

In addition to the specifications in IEC 60060-1 (2011), uniform sprinkling and wetting are set on the insulator by visual inspection. The measurement is carried out after the pre-stress time with continuous rain. The test setup is shown in Fig. 9.

The pollution layer is moistened with a modified clean fog specified in CIGRE Technical Brochure 481 (2011). For this purpose, the artificially polluted insulator is fogged with a non-conductive fog at room temperature in a fog chamber (Fig. 10) with the following parameters:

- Generation of the fog: 2 Defensors type 505, Defensor AG Pfäffikon
- Volume of fog chamber: 4.5 m^3
- Precipitation rate: 0.03 ml/(cm^2 - h)

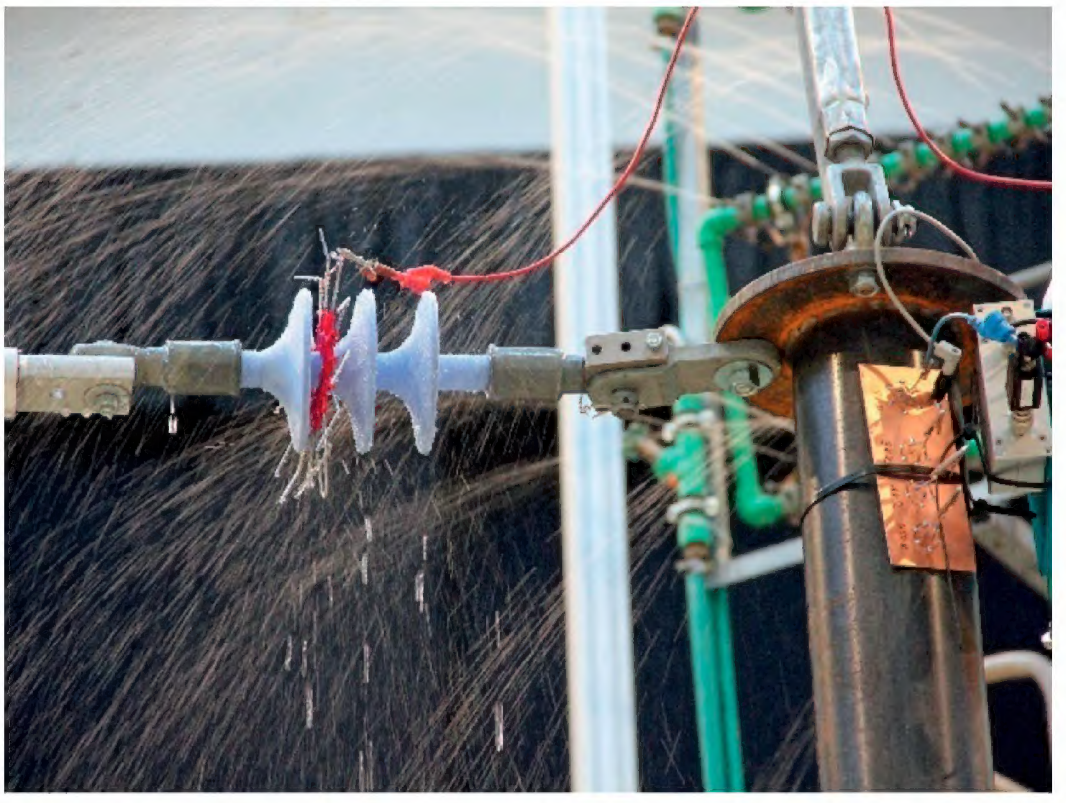

Figure 9. Investigation of the insulator during the rain test.

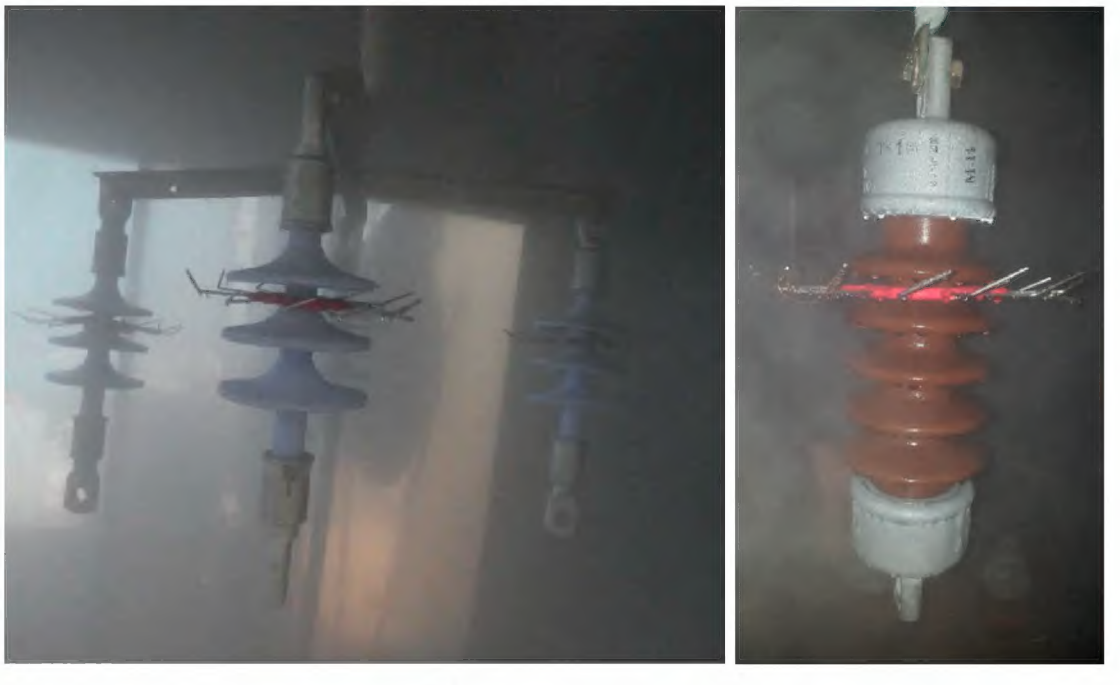

Figure 10. Insulator in the fog chamber (left: polymeric, right: porcelain).

Figure 11. Iced insulator.

- Fog conductivity: 2 μS/cm
- Time of fogging without voltage stress condition 2 h

The generated fog leads to slow moisture penetration of the pollution layer without washing off. This simulates the dewing or fogging of pollution layers in reality.

The approach described by the Institute of Electrical and Electronics Engineers (IEEE) Task Force on Insulator Icing Test Methods in Farzaneh et al. (2003) is used to simulate a practical ice formation. This publication presents the state of knowledge developed by the IEEE Task Force together with the CIGRE Ice/Snow Tasks Force. According to Bär (2016), a glaze with a transparent and clear appearance and cylindrical ice is proposed for investigations with bird protection fittings. This icing is classified as the most critical variant and occurs at low wind speeds. The results of the icing procedure are shown in Fig. 11.

Measurements and data analysis

The current measurement is done as described using a resistor as a shunt and recorded by a transient recorder.

In Fig. 12 the transient current behavior at the moment of contact of the small bird with the animal deflector is shown. What is remarkable is the very fast discharge of the charge carriers, which are stored at the metal electrodes of the animal deflector. The rise time of the measured values is approx. 2 ns. The value of the peak current shows up to 10 s of amperes. The whole impulse with its damped behavior lasts up to 30 ns.

In contradiction to the very fast transient behavior at the moment of the contact, the steady-state current follows in line with the theory of the source frequency of 50 Hz and is shown in Fig. 13. The polymeric insulator with the animal deflector at clean surface and under dry conditions shows a clear capacitive behavior with a peak current of approx. 20 μA.

For the evaluation of the measurement results the following values were derived from the measurement data:

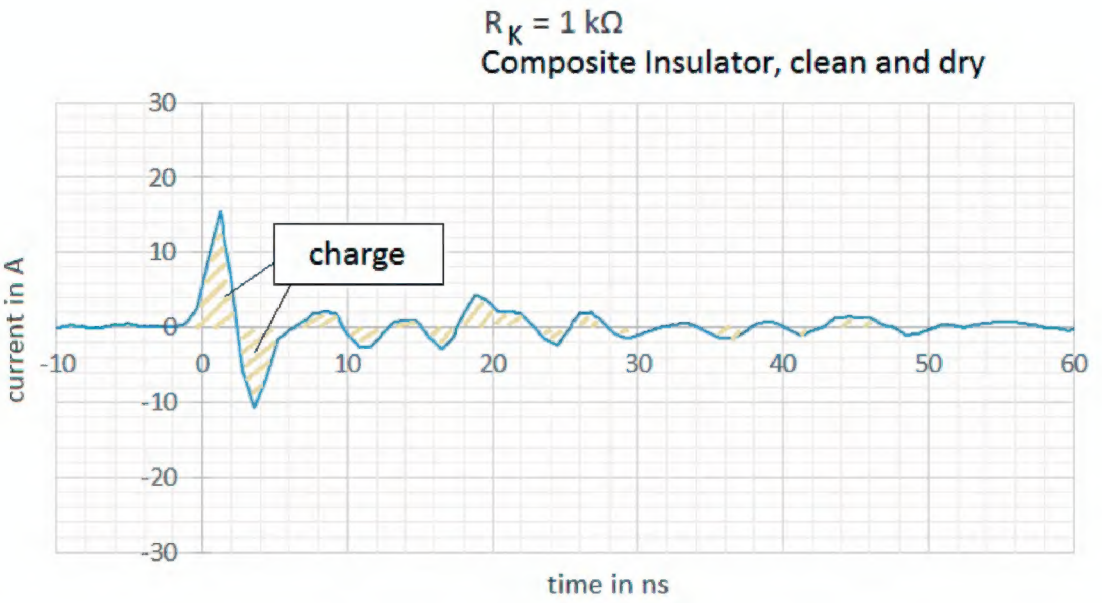

Figure 12. Transient current behavior at the moment of contact with a polymeric insulator.

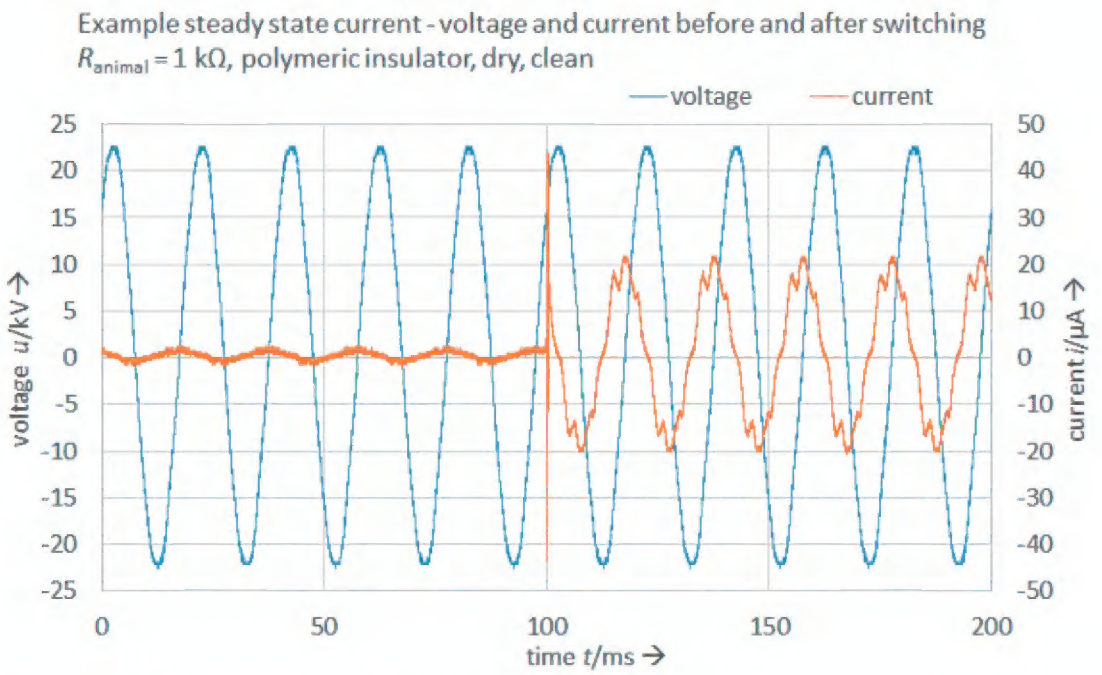

Figure 13. Steady-state current behavior for a polymeric insulator..

- the transient current in the moment of the contact of the animal deflector, the carried charge, and the energy with the equations are used:

$$Q = \int |i(t)| \cdot dt$$

$$E = R \cdot \int i(t)^2 \cdot dt$$

- the steady-state conditions, the root mean square value of the current is used

Evaluation criteria

Based on the theoretical considerations and the measured values, three basic scenarios have to be distinguished with regard to the exposure of birds and small animals to electric currents flowing through the KTA:

1. transient current by transport of the charge from the animal deflector at the time of contact with the animal deflector by the small bird or small animal (time range few 10 ns) – see Fig. 14
2. stationary current when the bird or small animal continuously touches the animal deflector (time range ms) - see Fig. 15
3. electric arc as a result of flashover and flow between high-voltage contact and earth (so-called earth fault) on the bird or small animal (time range ms) - see Fig. 16

The third scenario with the current or direct thermal effects of the arc on a bird or small animal leads to direct damage to the living creature in addition to the electrical effects, especially due to the thermal effects. The occurrence of this scenario shall be prevented. Consideration of limit and guide values for this scenario is not expedient.

For the assessment of the measured values, the following values are defined for the respective scenarios presented in this project:

Reference stimulus threshold

The "reference value stimulus threshold" describes a current value above which the animal can feel a biological effect. Current values that fall below this value are not noticeable due to biological effect mechanisms.

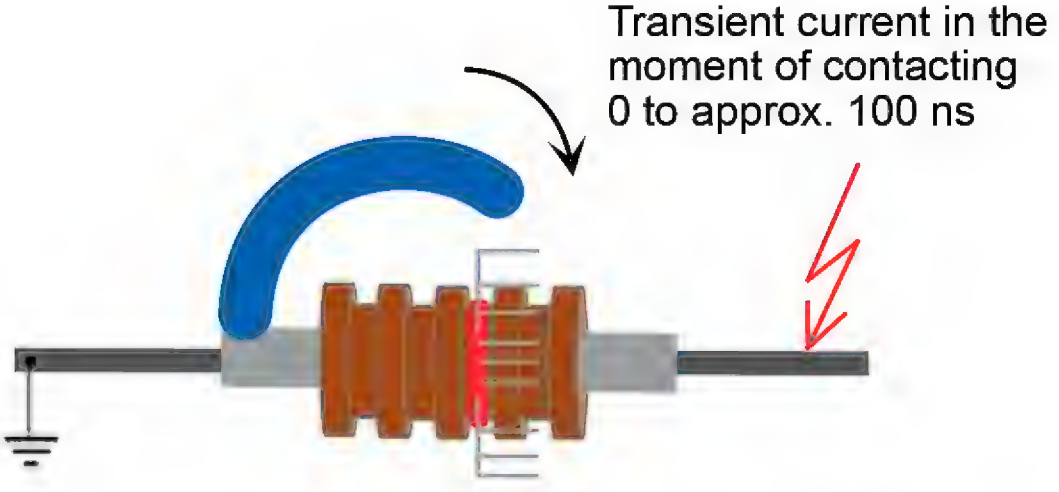

Figure 14. transient current when the switch is closed (bird or small animal is indicated with a bow).

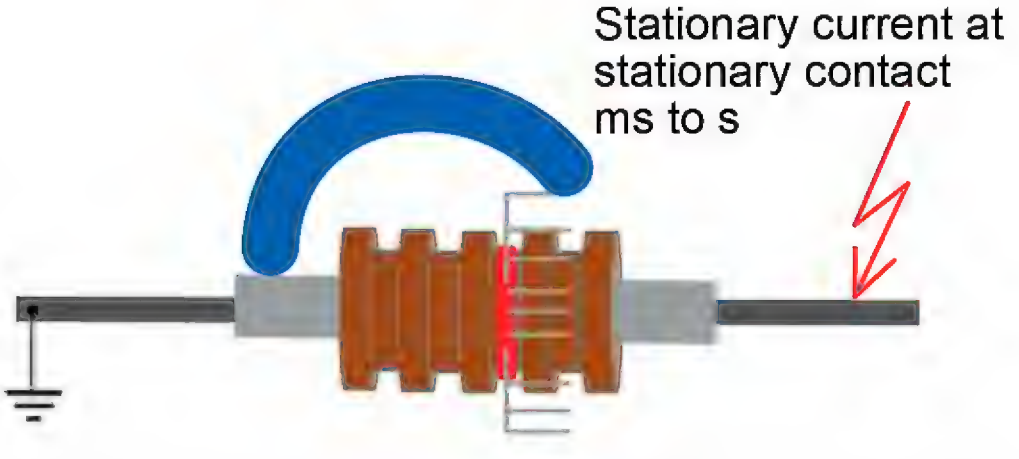

Figure 15. Flow with stationary current during continuous contact (bird or small animal is indicated with an arc).

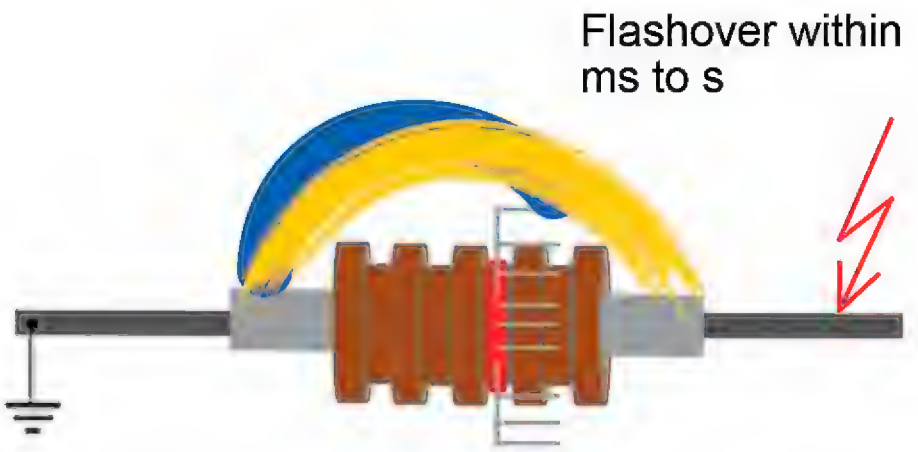

Figure 16. Flashover at the KTA (bird or small animal is indicated with an arc).

Hazard threshold

If the "threshold value danger" is exceeded, it can be assumed that the bird will be directly or indirectly harmed by the electrocutions.

In the following, the determination of limit and reference values for current will therefore concentrate on scenarios 1 (transient current) and 2 (stationary current).

The values are gained by using a detailed literature study and intensive discussions in the interdisciplinary project advisory group and summarized in Table 2. A short overview of the based literature is mentioned in (Osypka (1963), DIN EN 60335-2-76 (VDE 0700-76) (2015), "weidezaun.info" VOSS GmbH & Co. KG (2019), DZSF (2019), Meyer and Jeromin (2016), Jeromin et al. (2013), Operational Manual hotShock 300 (2017), VDE-AR-N 4210-11 (2011), Pearce et al. (1982), Leitgeb (2000)). The detailed analysis is described in the research report Görlich et. Al. (2021).

Results

Based on the measurement results and its derived values, the evaluation was done by comparing with the reference values according to Table 2. The evaluation results are presented in Table 3.

In detailed for each insulator following summarized results can be found:

Table 2. Concluded reference stimulus threshold and hazard threshold.

	Transient current pulse stress	Stationary current stress
Time interval of the stress	few 10 ns	ms to s
Hazard threshold	1 Joule	2 mA
	Osypka (1963), DIN EN 60335-2-76 (VDE 0700-76) (2015), "weidezaun.info" VOSS GmbH & Co. KG (2019), DZSF (2019), Meyer and Jeromin (2016), Jeromin et al. (2013), Operational Manual hotShock 300 (2017)	VDE-AR-N 4210-11 (2011)
Reference stimulus threshold	Not available	500 µA
		Pearce et al. (1982), Leitgeb (2000)

Table 3. Overview of measured values compared with thresholds of Table 2.

Insulator Typ	Insulator Condition	Ambient	Reference Stimulus Threshold	Hazard Threshold	
			Stationary current stress Time interval of the stress ms to s	Stationary current stress Time interval of the stress ms to s	Transient current puls stress Time interval of the stress few 10 ns
POLYMERIC INSULATOR	Cleaned	Dry	Not exceeded	Not exceeded	Not exceeded
		Rain	Not exceeded	Not exceeded	Not exceeded
		Ice	Not exceeded	Not exceeded	Not exceeded
POLYMERIC INSULATOR	light polluted	Dry	Not exceeded	Not exceeded	Not exceeded
		Rain	Not exceeded	Not exceeded	Not exceeded
		Fog	Not exceeded	Not exceeded	Not exceeded
POLYMERIC INSULATOR	heavy polluted	Dry	Not exceeded	Not exceeded	Not exceeded
		Rain	Not exceeded	Not exceeded	Not exceeded
		Fog	Not exceeded	Not exceeded	Not exceeded
PORCELAIN INSULATOR	Cleaned	Dry	Not exceeded	Not exceeded	Not exceeded
	light polluted	Fog	**Exceeded**	**exceeded**	Not exceeded
	heavy polluted	Fog	**Exceeded**	**exceeded**	**Not available** Due to flashover no measurement was possible

Polymeric insulator

For the polymeric insulator investigated for the risk at the moment of contact it can be concluded that for all environmental conditions the energies measured at the body resistance are below the hazard limit value of 1 J. The current pulse of the investigated polymeric insulators (or comparable types) is below the hazard limit value.

For the polymeric insulator examined for the risk at stationary contact it can be concluded that for all insulator situations that the currents measured at the body resistance are below the hazard limit of 2 mA. This can be attributed to the hydrophobic properties of polymeric insulators. When the polymeric surface is wetted, no closed pollution layer is formed, but instead, individual droplets are formed, which greatly reduces the current. This effect also occurs with polluted polymeric insulator surfaces since the layer of dirt also takes on a water-repellent effect due to the hydrophobic transfer.

For the evaluation of the stimulus results in the moment of contact, it was not possible to determine a reference value for the stimulus threshold for pulsed flow. For this reason, no statement can be made about the triggering of the receptors on the basis of the measured values. Thus, it cannot be conclusively clarified whether small birds react when touching the animal deflector.

For the polymeric insulator investigated for the stimulus result at stationary contact it can be concluded for all insulator states that the currents measured at the body resistance are below the defined reference value of the stimulus threshold of 500 µA.

Porcelain insulator

For the examined porcelain insulator for the risk at the moment of contact it can be concluded that for the insulator states cleaned and light-polluted (in case of moisture

penetration with mist) that the energies measured at the body resistance are below the limit value of hazard of 1 J. An evaluation of the heavily polluted, wetted fog porcelain insulator is not possible due to the spontaneous flashover.

For the examined porcelain insulator for the risk at stationary contact it can be concluded that for the insulator states cleaned and dry that the currents measured at the body resistance are below the limit value of the risk of 2 mA. For the examined porcelain insulator, it can be determined for the insulator states light-polluted wetted with fog that the currents determined at the body resistance are above the limit value hazard of 2 mA. In the case of a heavy-polluted porcelain insulator, spontaneous flashover occurs with a current-starved arc, whereby a bird would be exposed to thermal damage in addition to electrical damage.

For the evaluation of the stimulus results at the moment of contact, no reference values for the irritation threshold could be determined. For this reason, no statement can be made about the triggering of the receptors based on the measured values.

For the evaluation of the stimulus results for stationary contact for the examined porcelain insulator, it can be determined for the insulator states cleaned dry that the currents determined by measurement on the body resistance are below the defined reference value of the stimulus threshold of 500 μA. It can be assumed that no stimulus is triggered due to the electrical flow. In the case of the examined light pollution wetted by fog, the reference value of the stimulus threshold but also the danger threshold is exceeded. In the case of a heavily polluted porcelain insulator, spontaneous flashover with a high-current arc occurs, whereby a bird would be exposed to thermal damage in addition to electrical damage.

Discussion

Compared to other transport infrastructures, electric railways have unique features that can cause specific hazards for birds. Overhead line systems of electric railways provide birds with a variety of resting places. In particular, the simultaneous contact with system components of different electrical potentials possesses a risk of damaging currents flowing or even triggering a short circuit for birds. The company DB Netz AG is increasingly using an animal deflector (German: Kleintierabweiser – KTA) mounted on the insulating part of the high-voltage insulators. The animal deflector does not provide protection for larger birds and does not meet the requirements of the Federal Nature Conservation Act (§ 41 BNatSchG, according to which only constructive measures are to be provided for new installations). They may, therefore, only be used for retrofitting existing plants. This investigation was done because no measurement results of the electrical current at animal deflectors in different conditions are available. With these results a measurement-based evaluation of the effectiveness of the animal deflector is supported.

Basically, a distinction must be made between three scenarios:

- The bird touches the animal deflector, and the electrostatic discharge causes a transient impulse current through the small bird or animal (The time range of the discharge process is up to about 100 ns).

- The bird touches the KTA for a longer period (time range ms to s): A stationary electrical flow through the living being occurs.
- The contact with the bird causes a flashover with a corresponding thermal effect.

To assess the electrical flow through birds and small animals, hazard thresholds (damage) and reference values for the stimulus threshold for stationary electrical flow were determined based on literature research, physiological principles, and analogy relationships. A reference value for the stimulus threshold for transient impulse current could not be determined.

Regarding the examined polymeric insulator, the following conclusions can be made:

- No exceedance of hazard thresholds is detected;
- It is not possible to conclusively assess whether the stimulus threshold is triggered by transient impulse current (no reference value for the stimulus threshold could be determined);
- For these reasons, the use of investigated animal deflector (KTA) to the examined polymeric insulator type (or insulators of comparable design) can be recommended, since, based on the investigations, no danger to small birds and small animals can be identified.

For the examined porcelain insulator following conclusions can be done:

- No exceedance of hazard threshold value can be detected in clean and dry conditions;
- An exceedance of hazard threshold value can be detected when light-polluted and wetted by fog layer;
- The formation of a flashover can be observed in the case of heavy pollution and wetted by fog layer;
- Therefore, no recommendation is given for the application of the use of the investigated animal deflector (KTA) for the investigated porcelain insulator type (or insulators of comparable design).

However, besides the extensive investigations undertaken, the following areas can be listed as possible investigation areas:

- Other types of insulators (e.g. glass type cap and pin insulators, different lengths) and animal deflectors were not investigated. Therefore, it need to be added, that the behavior of the deflector and the effects to the small animals and birds depend on the insulator design and its material. For this reason, investigations needs to be done regarding different insulator designs or materials as well as pollution types.

- Besides the examined electrical mode of operation, the animal deflector may have a mechanical and optical mode of operation, whereby the investigations into the behavior of small birds and animals towards the animal deflector are not part of this research work. Further investigations to evaluate the optical repelling effect are necessary.

- For a better evaluation of the measured values, especially with respect to a reference value of the stimulus threshold, further physiological examinations are necessary.

Our preliminary results indicate that the use of an animal deflector (KTA) to the tested polymeric insulator and pollution severity can be recommended because, based on the investigations, no danger to small birds and small animals can be identified. However, the use of the animal deflector (KTA) for the tested porcelain insulator and pollution severity should not be recommended as they showed high animal hazards during pollution and fog conditions. However, these results cannot be transferred to other different insulator types and pollution severities. Investigate the electrical current to the used type of insulator and the expected severity of pollution is recommended..

Acknowledgements

We thank the "BMVI Network of Experts" of the Federal Ministry of Transport and Digital Infrastructure of Germany (BMVI) for funding through the Federal Railway Authority, Germany (project number 2018-U-10-1217). The authors also thank the interdisciplinary project advisory group for their discussions and valuable contributions in the project meetings.

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